TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TM- No. 727

THE THEORY OF THE STRANDGREN CYCLOGIRO

By C. B. Strandgren

l'Aérophile, Vol. 41, No. 7, July 1933

Washington
November 1933

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM NO. 727

THE THEORY OF THE STRANDGREN CYCLOGIRO*

By C. B. Strandgren

INTRODUCTION

The general classification of aircraft is: ornithopters, helicopters, and airplanes.

The "Strandgren wheel" belongs to none of these categories. It employs for lift and propulsion alike a pair of paddle wheels with blades revolving on a transverse axis.

Several aircraft, based on a similar principle, have been studied elsewhere, but for none the experiments appear to have been so extensive as for this one.

Each wheel consists of a certain number of equidistant blades arranged around the horizontal axis of rotation and parallel to this axis. Each blade is fixed so as to be able to feather about an axis parallel to its span at the same time as it turns about the general axis of rotation. A system of controls permits feathering or change of incidence of the blades to conform to the desired effect: hovering, lift and propulsion combined, gliding descent, vertical descent in autorotation, etc. Moreover, a differential control of the wheels insures any desired evolution of the aircraft about its center of gravity.

The Strandgren flying machine has no wings, no propeller or control surface other than its two wheels with its controls. It can fly vertically, horizontally, forward or backward, and at any speed between zero and a maximum. It has, like the airplane, an economical speed represented by a certain ratio between forward speed and the speed of rotation of the blades, but it flies at any other speed and can, in particular, hover in the air.

---

*"Principe et calcul des roues sustentatrices et propulsives rationnelles." l'Aérophile, July 1933, pp. 208-216.

Its controllability is incomparably superior to that of an airplane, since the whole surface of the blades driven at high speed serves for maneuvering. The incidence can, in fact, be changed instantaneously without modifying the position of the aircraft, which always remains the same.

Descent with engine stopped should not present any difficulty - no more than landing - which can be effected at any inclination, including the vertical.

Hereinafter follows the general theory of wheels with blades rotating about a transverse axis which, we believe, is the first time that this theory has been made public.

Much very important practical information on rotating wings of the category of lifting wheels has been obtained by the author, thanks to the numerous tests made at the Institut Aérotechnique de Saint-Cyr, by means of different small-scale models constructed with the cooperation of the Office National des Inventions et de la Société "L'Expansion Franco-Scandinave" relations.

Following these systematic experiments, the Lioré and Olivier airplane company has built a full-scale model.

The object of this paper is not to disseminate the theoretical aspect and general principle of the wheels, and particularly, the results of these experiments, but to show how the lift and the propulsion are obtained.

The problem is governed by a rigorous kinematic condition which every rotating wing of this type should satisfy.

In a wheel, each blade describes a curve in the air, and one says that this curve is a more or less abridged cycloid, according to the relative speed of the aircraft with respect to the fluid. The kinematic representation of the motion of the blades with respect to the fluid is obtained by making a circle (rotor) roll on a straight line (directrix), and one knows then that the normals to the blade trajectories at a given instant, all pass through the point of contact of the rotor with the directrix which, by definition, is the instantaneous center of rotation.

The normal to each blade should form with the normal to the trajectory of this blade an angle which is the angle of incidence of the blade (fig. 1).

Now, what should these angles of incidence be along the trajectory, so that a mean resultant of desired magnitude and direction can be produced on a blade? This is what we shall attempt to establish by analysis.

The fact that the trajectory of the blade relative to the air - setting aside irregularities of the wind - is a cycloid, which sets up the fundamental kinematic condition to which the angular motion of this blade is subjected.

The circle of radius R and of center o represent a wheel. Several blades (n) are assumedly disposed on its periphery. One blade or airfoil in the illustration is figured with axis of articulation in o_1. All blades have identical motion and the aerodynamic resultant of each blade is the same in direction and magnitude, so that it suffices to discuss only one blade.

Under the effect of the forces which these blades produce, we assume that the wheel flies at a speed V_1. On account of disturbances of the air adjacent to the wheel the mean speed of air V passing across the wheel, is more or less different from V_1, according to the case. When the aircraft is in horizontal flight at high speed, V differs little from V_1, but in hovering, V_1, which is the speed of the aircraft is, by definition, zero, whereas V - the downward speed of the air and traversing the wheel - has a relatively great value. Speed V may be defined as the mass of air (M) passing through the wheel per second:

$$M = \rho S V$$

wherein ρ = density, and S = projected surface of a cylinder formed by the wheel, or, in other words, its diametrical area.

Now, in order to study and analyze the aerodynamic reactions on a wheel, may we apply to each blade the conventional lift (C_z) and drag (C_x) coefficients? Our experiments prove that we can. Theoretically, we ignore what they reveal.

The only difficulty lies in the fact that the air speed on a wing changes continuously along with the slope of the trajectory. For the case of constant speed and slope, Carafoli* has shown that the aerodynamic coefficients obtained in rectilinear stream, can be employed.

To form the resultant of the air loads on a wheel, one may either add vectorially the forces on each blade, the vertical component supplying the lift and the horizontal component the forward speed, or else compute by integration the mean force applied at a blade during one turn of the wheel. We preferred the latter.

The forces on a blade are:

$$\frac{\rho}{2}\, s\, W^2\, C_z \quad \text{normal to trajectory} \tag{1}$$

$$\frac{\rho}{2}\, s\, W^2\, C_x \quad \text{tangential to "} \tag{2}$$

s = area of blade and W = aerodynamic speed which, of course, is tangential to the trajectory. By projecting these forces first on an axis normal to V, then on an axis parallel to V, we obtain the mean force on one blade during one turn of the wheel:

$$F_n = \frac{1}{2\,\pi} \int_0^{2\pi} \frac{\rho}{2}\, s\, W^2\, (C_z \cos \alpha + C_x \sin \alpha)\, d\,\beta \tag{3}$$

$$F_t = \frac{1}{2\,\pi} \int_0^{2\pi} \frac{\rho}{2}\, s\, W^2\, (C_z \sin \alpha - C_x \cos \alpha)\, d\,\beta \tag{4}$$

To find the forces on all blades, we multiply these quantities by the number of blades (n) or, which is the same, consider s as the total area of the blades.

The formula on the average is said to give, in general, different results, according to the chosen independent variable. The result conforms to the reality obtained with an independent variable proportionate to the time. The angle β meets this condition since $d\beta/dt = \omega$ is the angular velocity of the wheel, which is constant.

Therefore, we have:

F_n, the normal component of V,

---

*"Aerodynamique des ailes d'avions," Chiron, editor, Paris.

F_t, the tangential component of V,

α, the angle formed by the normal of the trajectory with the vertical,

s, total surface of the blades.

Supposing that F_n, F_t, and φ, the angle of the vector V with the horizontal, are known: then it is easy to obtain the vertical and horizontal components of the resultant which we designate by P and T, respectively.

$$P = F_n \cos \varphi + F_t \sin \varphi$$

$$T = - F_n \sin \varphi + F_t \cos \varphi$$

P is the lift and T the difference between the thrust and the drag. When the horizontal speed of the aircraft is constant, whatever it may be, T is obviously zero.

By resolving (5) with respect to F_n and F_t, we have

$$F_n = P \cos \varphi - T \sin \varphi$$

$$F_t = P \sin \varphi + T \cos \varphi$$

which, for the case of uniform speed, is reduced to

$$\begin{aligned} F_n &= P \cos \varphi \\ F_t &= P \sin \varphi \end{aligned} \qquad (6)$$

As to the direction of flight, it is dependent only on F_n and F_t as these equations show. In order to find whether one can fly in any direction whatsoever, in the vertical plane with such aircraft, it suffices to show that, in equations (3) and (4) by taking for C_z a certain function of α, one can give F_n and F_t the desired values.

But first we give the term of the aerodynamic speed W as a function of the blade setting. With ρ as the radius moving from the instantaneous center of rotation I of a blade, it is readily seen that speed W, tangential to the blade trajectory, is:

$$W = \omega\ \rho$$

(ρ must not be confused with the density).

Furthermore, let r be the radius of the rotor and R the radius of the wheel. We call

$V_r = \omega R$ the speed of the blades in the relative motion.

and $V = \omega r$ the mean speed of the air passing through the wheel, as defined above.

These data forthwith, give:

$$W^2 = V_r^2 + V^2 + 2\ V\ V_r \cos \beta$$

whence V_r and V are constants for a given flight attitude, β being the only variable.

The mean of W^2 during one turn will be

$$W_m^2 = V_r^2 + V^2$$

and W varies between the maximum and minimum limits

$$V_r + V \text{ and } V_r - V,$$

In the integrals of F_n and F_t ((3) and (4)), ρ, s, and W^2 are always positive data, such that the value of these integrals depend primarily on the products $C_z \cos \alpha$ and $C_z \sin \alpha$ and on the sign of these products in the integration interval (disregarding for a moment the term C_x).

Supposing one wishes to produce only the force F_n: in which case it is obvious that no matter what the law of variation of C_z as function of α, to insure maximum integral, the product $C_z \cos \alpha$ must always have the same sign. Thus C_z becomes positive or negative at the same time as $\cos \alpha$. Such a law can be realized by putting

$$C_z = a \cos \alpha$$

where a is a constant.

One can also make $C_z = a_1 \cos^3 \alpha$; or the sum of a series of uneven power terms of $\cos \alpha$, terms which equally change sign with $\cos \alpha$. But, when integrating, it is seen that with $C_z = a \cos \alpha$ the integral becomes maximum.

If it is desired to produce F_t alone, then the product $C_z \sin \alpha$ must retain the same sign and one is led to make $C_z = b \sin \alpha$, etc.

Consequently, to produce a force in direction κ, we make

$$C_z = A \cos (\alpha - \kappa)$$

or

$$C_z = a \cos \alpha + b \sin \alpha$$

A and κ being parameters and $a = A \cos \kappa$ $b = A \sin \kappa$.

By changing the parameters A and κ, one can give to a and b any desired system of value. It is, moreover, in this that the piloting of the aircraft consists. Through interconnected and differential controls the pilot can change these parameters in each wheel.

By introducing

$$W^2 = W_m^2 + 2 V V_r \cos \beta$$

and

$$C_z = a \cos \alpha + b \sin \alpha$$

in F_n and F_t by expressing $\sin \alpha$ and $\cos \alpha$ as function of $\sin \beta$ and $\cos \beta$

$$\cos \alpha = \frac{V + V_r \cos \beta}{\sqrt{W_m^2 + 2 V V_r \cos \beta}}$$

$$\sin \alpha = \frac{V_r \sin \beta}{\sqrt{W_m^2 + 2 V V_r \cos \beta}}$$

which, after integration and calculation, gives

$$\left.\begin{aligned} F_n &= \frac{\rho}{2}\, s \left[W_m{}^2 \left(\frac{a}{2} + \frac{2\,ab}{\pi\lambda}\,0.2\right) + 2\,V\,V_r \left(\frac{a}{3} + \frac{2\,ab}{\pi\lambda}\,0.25\right)\right] \\ F_t &= \frac{\rho}{2}\, s \left[W_m{}^2 \left(\frac{b}{2} - \frac{C_{xo}}{2} - \frac{0.1\,a^2 + 0.2\,b^2}{\pi\lambda}\right) - 2\,V\,V_r \left(\frac{b}{10} + 0.45\,C_{xo} + \frac{0.1\,a^2 + 0.2\,b^2}{\pi\lambda}\right)\right] \end{aligned}\right\} (7)$$

To express C_x in these formulas, we put

$$C_x = C_{xo} + \frac{C_z{}^2}{\pi\lambda}$$

where λ = aspect ratio of airfoil and C_{xo} = airfoil drag at zero lift.

According to these formulas, F_n appears to depend primarily on a and F_t on b, and by changing these coefficients, the components F_n and F_t can be varied (fig. 2). The nature of the a and b coefficients is readily determined.

We used to put $C_z = A \cos(\alpha - x)$, so that C_z maximum = A; A is the maximum of C_z during one rotation.

But, as already pointed out, A is a variable parameter, being able to assume any value between zero and C_z maximum of the polar of the employed airfoil.

Thus we have: $a = C_{z\,max} \cos x$,

$$b = C_{z\,max} \sin x.$$

By limiting ourselves to the principal terms in (7), it becomes

$$F_n = \frac{\rho}{2}\, s\, W_m{}^2\, \frac{a}{2}$$

(a value inferior to reality since the positive terms are being disregarded);

$$F_t = \frac{\rho}{2} s W_m^2 \frac{b}{2}$$

(a value superior to reality, where a and b are divided by 2).

Putting $$C_z \text{ mean} = \frac{1}{2\pi} \int_0^{2\pi} a \cos^2 \alpha \, d\alpha$$

we find that
$$\frac{C_z \max}{2} = C_z \text{ mean} \qquad (8)$$

during one cycle, which for convenience is designated by C_z.

Now we have:

$$F_n = \frac{\rho}{2} s W_m^2 C_z \cos \kappa$$

$$F_t = \frac{\rho}{2} s W_m^2 C_z \sin \kappa$$

To determine lift P in flight with uniform speed but for any flight-path direction, we simply write these values of F_n and F_t in formulas (5):

$$P = \frac{\rho}{2} s W_m^2 C_z (\cos \kappa \cos \varphi + \sin \kappa \sin \varphi)$$

and, the speed being uniform,

$$T = 0 = \frac{\rho}{2} s W_m^2 C_z (- \cos \kappa \sin \varphi + \sin \kappa \cos \varphi).$$

The last operation yields:

$$\frac{\sin \varphi}{\cos \varphi} = \frac{\sin \kappa}{\cos \kappa}$$

whence $\varphi = \kappa$, and by adding this result in the first, it becomes

$$P = \frac{\rho}{2} s W_m^2 C_z \qquad (9)$$

This formula is identical in form to that of an airplane flying at horizontal forward speed W_m, but utterly unlike as to interpretation for a wheel, since

$$W_m^2 = V_r^2 + V^2, \tag{10}$$

the sum of the squares of the tip speed of the blades and of the velocity of the air passing through the wheel.

In a wheel, formulas (9) and (10) hold good for every straight flight path, the vertical included, since we have imposed no condition on φ. Be it noted that parameter A was supposed to be positive. The result of making it negative, which is possible, is to orient the resultant of the wheel toward the ground. A should be positive to insure a lift.

The equation $\kappa = \varphi$ permits the identification of κ with the angle φ of the flight direction to the horizontal. To change this direction the pilot changes κ without modifying A. The change in A is not prescribed except with the change of weight P, of the aircraft.

By this simple argument of limitation to the principal terms in F_n and F_t, we underestimated F_n and overestimated F_t, so that in reality there is a certain difference between κ and φ and a certain variation to be given to A when φ is changed, but it is apparent that the pilot remains master of the resultant of the wheel in magnitude and direction.

The essential condition in a wheel for obtaining a significant and steerable result is obviously that the wheel must turn. The rotation is obtained by means of an engine which, however, may accidentally stop. And then the question arises as to whether the wheel is capable of autorotation in vertical descent without power.

To express this possibility in mathematical form, we write the formula of the mean moment of the forces on the blades with respect to the wheel center O. The forces on one blade are:

$$\frac{\rho}{2} s\, W^2\, C_z \quad \text{and} \quad \frac{\rho}{2} s\, W^2\, C_x$$

and their moment:

$$M_o = \frac{\rho\ s}{4\ \pi} \int_o^{2\pi} W^2\ (C_z\ r\ \sin\alpha$$
$$+ C_x\ R \sqrt{1 - e^2 \sin^2\alpha})\ d\ \beta,$$

where r = radius of rotor, R = radius of the wheel, and $e = r/R$.

Restricted to the principal terms, the integration gives

$$M_o = \frac{\rho}{2}\ s\ W_m^{\ 2}\ R \left[\frac{b}{2}\frac{V}{V_r} + C_{xo}\left(1 - \frac{e^2}{4}\right) + \frac{a^2}{2\pi\lambda}\left(1 - \frac{e^2}{8}\right) + \frac{b^2}{2\pi\lambda}\left(1 - \frac{3}{8}\ e^2\right)\right] \tag{11}$$

Another more precise term of the moment is obtained by first taking the moment with respect to the instantaneous center of rotation, I, then adding the moment with respect to O on the blade applied at I.

$$M_o = \frac{\rho s}{4\pi} \int_o^{2\pi} W^2\ [C_x\ \rho + r(C_z \sin\alpha - C_x \cos\alpha)]\ d\beta \tag{12}$$

By definition (see (4)):

$$F_t = \frac{\rho\ s}{4\ \pi} \int_o^{2\pi} W^2\ (C_z \sin\alpha - C_x \cos\alpha)\ d\ \beta,$$

so that, finally

$$M_o = \frac{\rho\ s}{4\ \pi} \int_o^{2\pi} W^2\ C_x\ \rho\ d\ \beta + r\ F_t \tag{13}$$

With this (13) the power formula is readily obtained:

$$P_m = \omega\ M_o = \frac{\rho\ s}{4\ \pi} \int_o^{2\pi} W^3\ C_x + V\ F_t$$

since $\omega\ r = V$ and $\omega\ \rho = W$.

In this formula, valid for no matter what propeller, it is readily seen how the power is made up. The term in C_x represents the power absorbed by the drag of the blades according to the trajectories, and the product $V\ F_t$ is the effective or active power of propulsion.

Conformable to the adopted notation the latter is positive when V and F_t are of opposite directions. When F_t and V are in the same direction it is negative and, when that occurs, P_m may cancel out and become negative. Then the aircraft supplies power to the engine, or, if without power, accelerates the rotation of the wheel. In formula (7) for F_t, it is seen that it becomes negative for negative b, so that F_t forces of negative sign can be produced. When P_m is negative for a certain wheel speed - the engine being out of gear - the speed of rotation of the wheel increases until P_m cancels out. Now, we have the equation $P_m = \omega M_o$. As ω is by assumption other than zero, we have $M_o = 0$. With this equation, the value of b, giving the speed of autorotation desired, can be computed.

Reducing (11) to read

$$M_o = \frac{\rho}{2} s W_m^2 R \left(\frac{b}{2} \frac{V}{V_r} + C_x\right) = 0$$

the autorotation for a certain given speed V/V_r takes place when

$$\frac{b}{2} = -C_x \frac{V_r}{V} \tag{15}$$

By definition, $\frac{b}{2} = \frac{C_{z\,max}}{2} \sin \kappa = C_z \sin \kappa$. (See equation (8).)

Solution of κ: In vertical descent, we have $\varphi = -90^\circ$, and equations (6) give

$$F_n = 0 \qquad F_t = - P.$$

But, when $F_n = 0$, it is also necessary that $a = 0 = C_z \cos \kappa$, whence we deduce $\kappa = \pm 90^\circ$, so that $\sin \kappa = \pm 1$, of which it must take the minus sign because φ is negative (fig. 3). We have already seen that κ and φ have a setting of almost identical angles and, in this case $b/2 = - C_z$, so that (15) now becomes

$$- C_z = - C_x \frac{V_r}{V}$$

or

$$\frac{V}{V_r} = \frac{C_x}{C_z}$$

which represents the optimum ratio between V and V_r for autorotation in vertical descent without power (fig. 4).

Admittedly, there are trajectories for autorotation in descent other than vertical.

We have seen that, to render the wheel generatrix of the power and to orient F_t in the same direction as V_1 stipulates two conditions for autorotation in gliding flight; it suffices to make parameter b negative.

Since $b = A \sin \kappa$, which is obtained by taking κ between π and 2π in a certain zone, it follows that the values which $a = A \cos \kappa$ may assume are positive or negative according to whether κ lies between $3\,\pi/2$ and 2π or between π and $3\,\pi/2$ and zero for $\kappa = 3\,\pi/2$. Thus it is apparent that the condition where b is negative does not prevent the production of a positive or negative F_n component, which permits oblique descent in forward flight or backward flight (fig. 5).

All of the foregoing formulas contained the unknown velocity of the air passing through the wheel. This velocity can be determined by means of theorems of momentum and kinetic energy.

Let us resolve V for a given case of the aerodynamic resultant of the wheel or wheels R and an infinite velocity V_1 (absolute speed of the aircraft with the exception of the sign), no matter which. Let $M = \rho\, S\, V$ be the air mass passing through the wheel per second. For brevity, we use vectors. A dash over a letter denotes a vector.

The velocity at infinity with respect to the wheels, is V_1. Upon passing into the wheel as a result of the resultant $\bar{R}$, the speed is $\bar{V}$ and the pressure is increased. Upstream, where the pressure has become normal again, the speed is $\bar{V}_2$.

The application of the momentum theorem gives

$$\bar{R} = M\,(\bar{V}_2 - \bar{V}_1) \qquad \text{(a)}$$

The rise of kinetic energy per second denoted by Pu, is

$$P_u = M \frac{V_2^2 - V_1^2}{2}$$

but this power equals the work per second of the resultant $\bar{R}$, whence

$$P_u = \bar{R}\,\bar{V}, \text{ the scalar product of } \bar{R} \text{ and } \bar{V} \qquad (c)$$

$$= M\,(\bar{V}_2 - \bar{V}_1)\,\bar{V}$$

Formula (b) may be rewritten as

$$P_u = M \frac{(\bar{V}_2 - \bar{V}_1)\,(\bar{V}_2 + \bar{V}_1)}{2}$$

(scalar product).

This formula and (c) reveal that

$$\bar{V} = \frac{\bar{V}_2 + \bar{V}_1}{2} \qquad (d)$$

which enables us to determine $\bar{V}$ when $\bar{V}_2$ and $\bar{V}_1$ are given. $\bar{V}_1$ is known from the speed indicator, whereas $\bar{V}$ is unknown.

We determine $\bar{V}$ by means of (a), which gives

$$\bar{V}_2 = \frac{\bar{R}}{M} + \bar{V}_1$$

which, written in (d), becomes

$$\bar{R} = 2\,M\,(\bar{V} - \bar{V}_1), \qquad (e)$$

an equation with only one unknown $\bar{V}$, which can be resolved.

When $\bar{V}_1$ is horizontal, formula (c) yields forthwith, $P = 2\,M\,V_v$, V_v being the vertical component of $\bar{V}$, P the vertical component of $\bar{R}$.

When $\bar{V}_1 = 0$, the aircraft hovers, we have $P = 2\,M\,V = 2\,\rho\,S\,V^2$, wherefrom

$$V = \sqrt{\frac{P}{2\,\rho\,S}}\,.$$

Equation (e) permits the resolution of V in all cases.

The foregoing is thought to be a fair outline of the general principle and elementary theory of paddle wheels.

A rational wheel is a rotary airfoil system producing a force restrained in its plane of rotation, which is the plane at right angles to the evolutions of the aircraft. It is from this fact that enormous practical values appear which promise a more general application of aviation, particularly of privately owned aircraft: lift independent of the speed, vertical climb, great maneuverability and stability (according to analysis and wind-tunnel tests). The private owner would no longer be disturbed about ground conditions; besides, being able to hover as long as desired, he need no longer fear the fog.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

LEGENDS

FIGURE 1.-Angle of incidence.

FIGURE 2.-Rotor rotation.

FIGURE 3.-Polar in autorotation as obtained with model; should be better in full-scale model. Note that the minimum slope of gliding in this case is about 45°.

FIGURE 4.-Lift and horsepower curves in flight with constant engine speed.

FIGURE 5.-Illustration showing gliding flight in three different cases.

Similar Paddle-Wheel Systems

FIGURE 6.-The Rotalift of the Holland engineer, W. P. Van Lammeren; equipped with Cirrus Mk. II, it is alleged to have produced a lift of 770 kg (1,697.6 lb.). On another model a lift of 165 kg (363.8 lb.) was said to have been obtained with 14 hp., a tip speed of 19 m/s (62.3 ft./sec.), and a 16 kg (35.3 lb.) load per unit of surface.

FIGURE 7.-Photograph of the model.

FIGURE 8.-Rahn cyclogiro. The engine is a 240 hp. Wright Whirlwind.

FIGURE 9.-Model mounted on carriage at Saint-Cyr.

FIGURE 10.-Full-scale test at Argenteuil. (Lioré et Olivier.)

FIGURE 11.-View of complete aircraft.

FIGURE 12.-Model wheel tested at Saint-Cyr; part of hub removed showing the incidence (feathering) control mechanism in neutral.

FIGURE 13.-In position of combined thrust and lift.

FIGURES 14-22.-Figures 14-19 show details of the Platt invention, tested in the wind tunnel of the Massachusetts Institute of Technology, at the Daniel Guggenheim School for Aeronautics, and at Langley Field. A photograph of the New York University model is shown on the right.

Figures 20-22 show details of the Laskowitz patent. Note that a single eccentric, such as is employed here, is not sufficient to insure correct control of feathering. Strandgren's patents antedate all these patents.

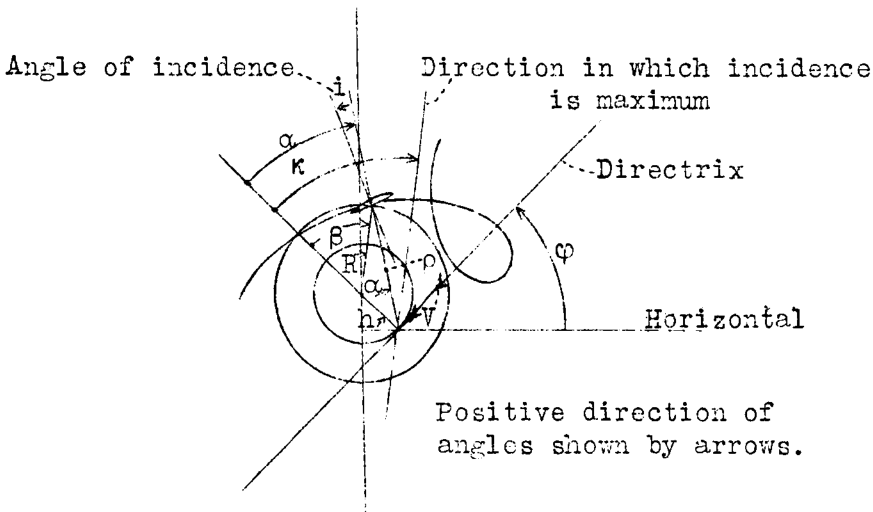


Figure 1.

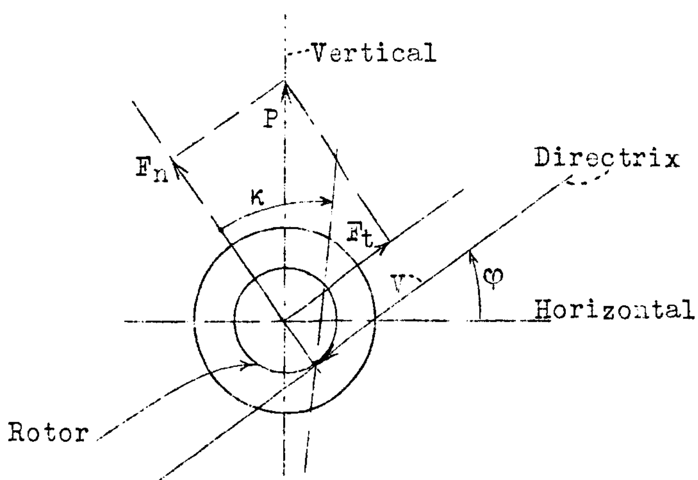


Figure 2.

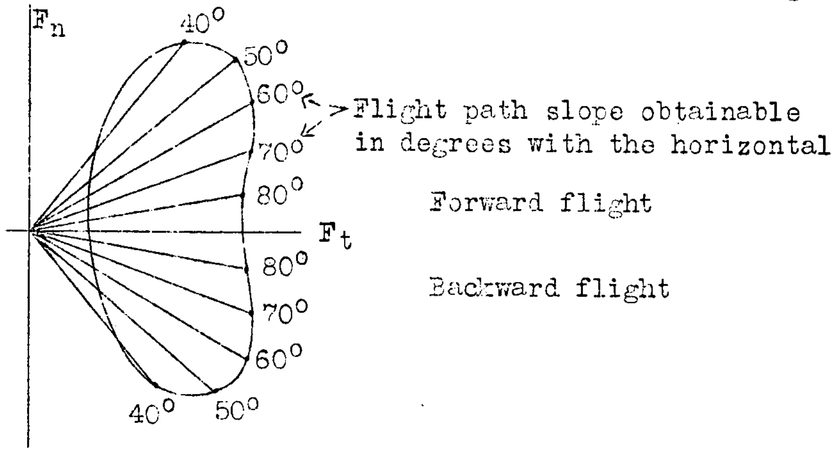


Figure 3.

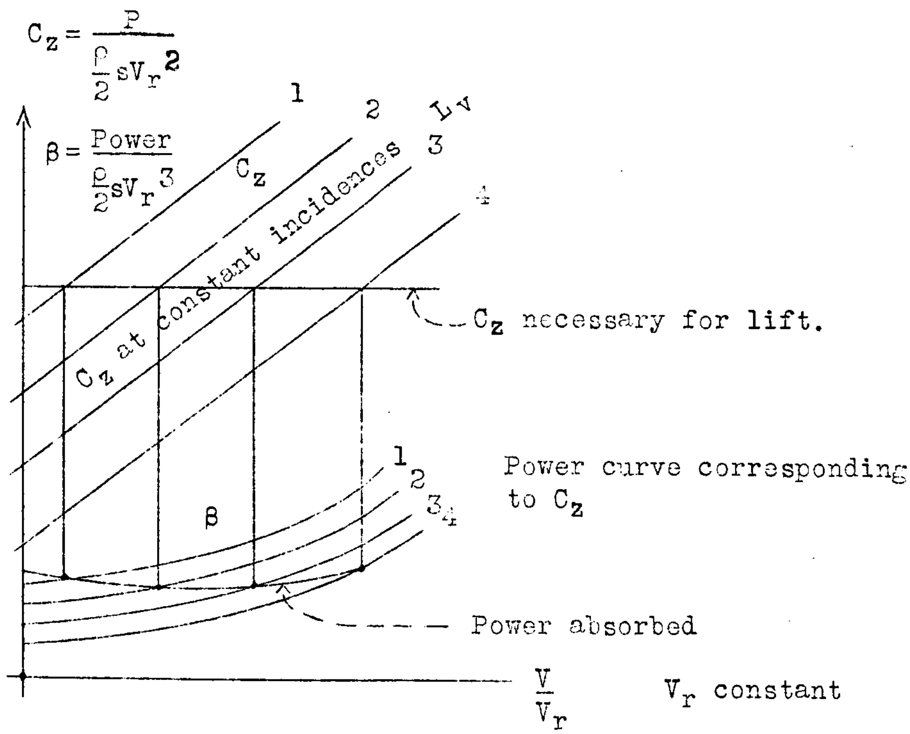
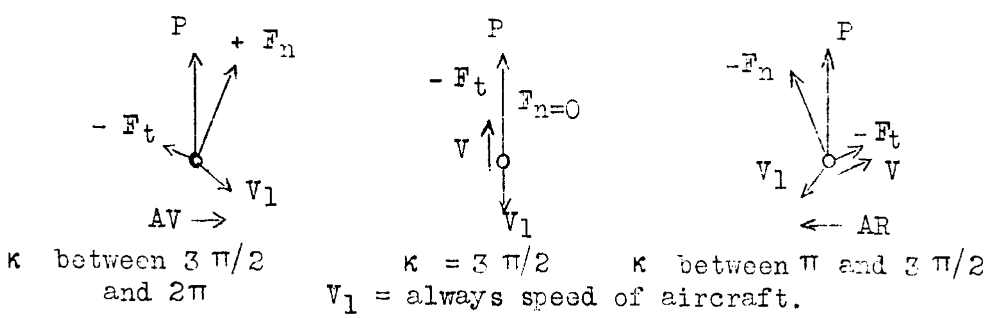


Figure 4.



V_1 = always speed of aircraft.

Figure 5.

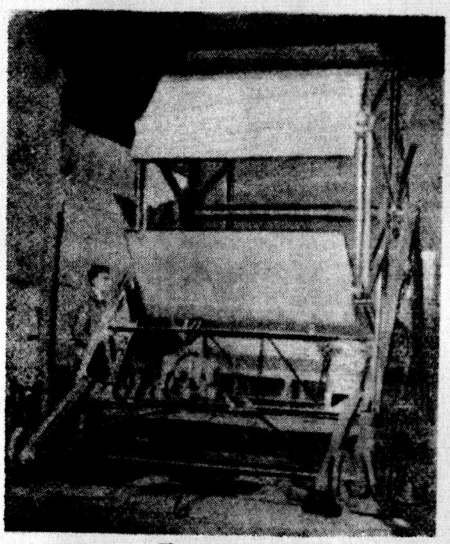


Figure 6.

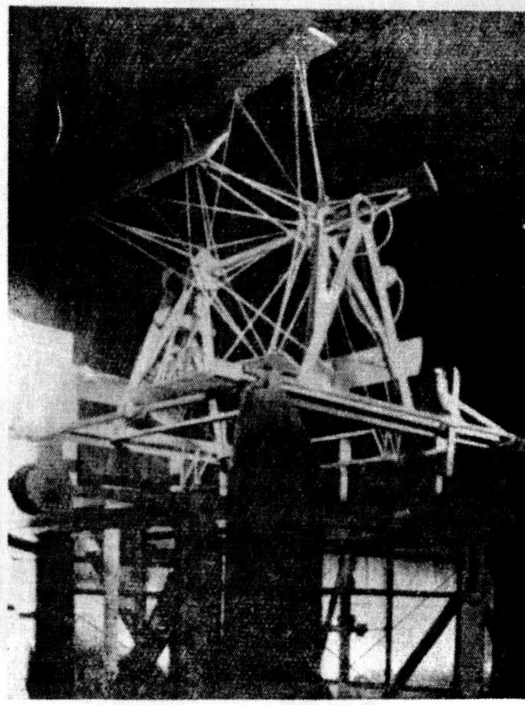


Figure 9.

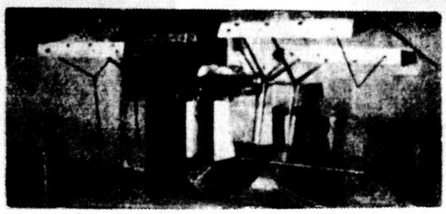


Figure 7.- Model of a Cyclogiro.

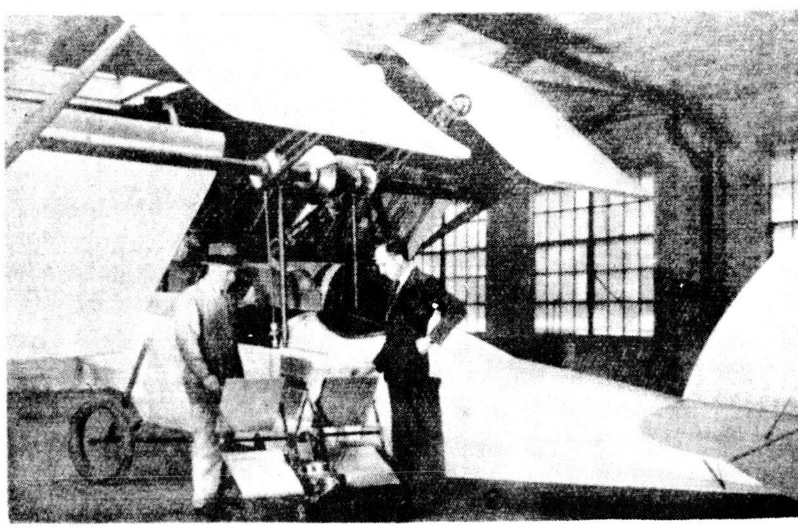


Figure 8.

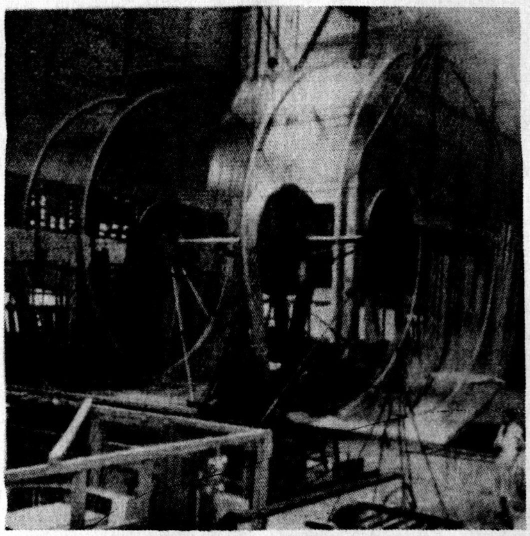


Figure 10.

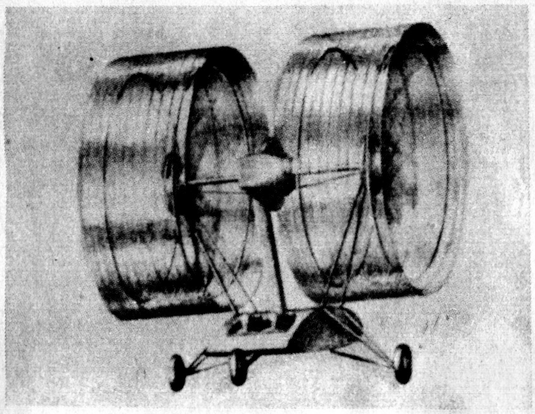


Figure II.

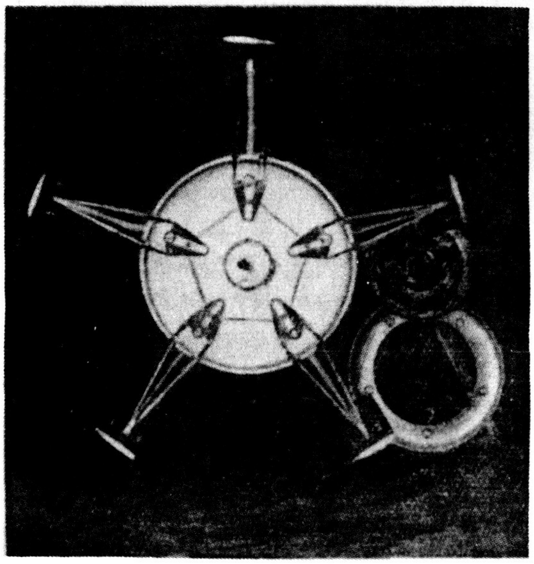


Figure 12.

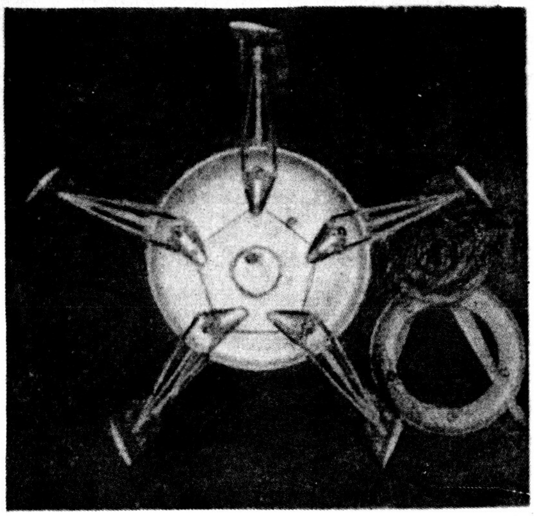


Figure 13.

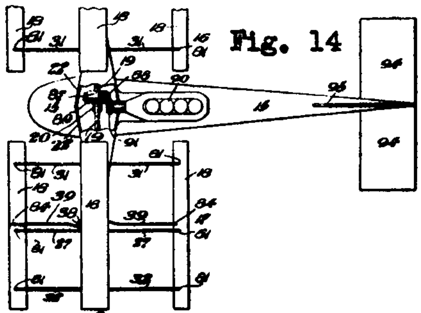


Fig. 14

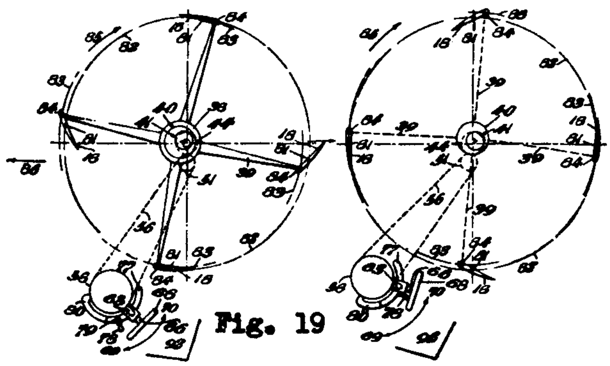


Fig. 19

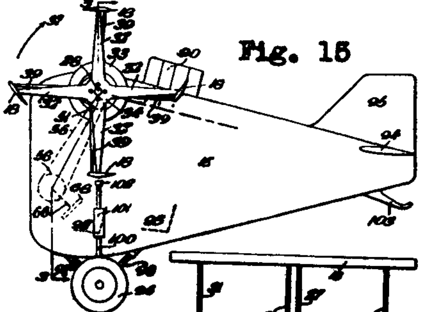


Fig. 15

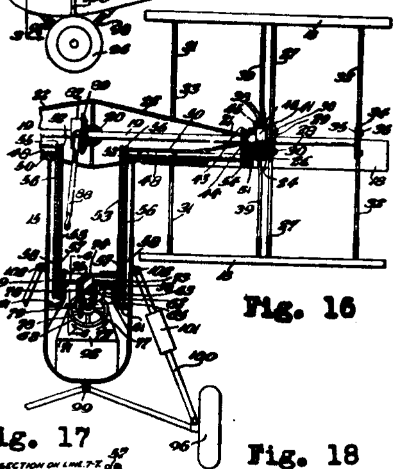


Fig. 16

Fig. 17

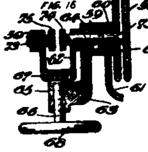
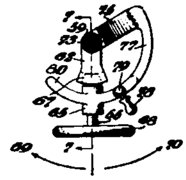


Fig. 18



Aviation Engineering

Fig. 20

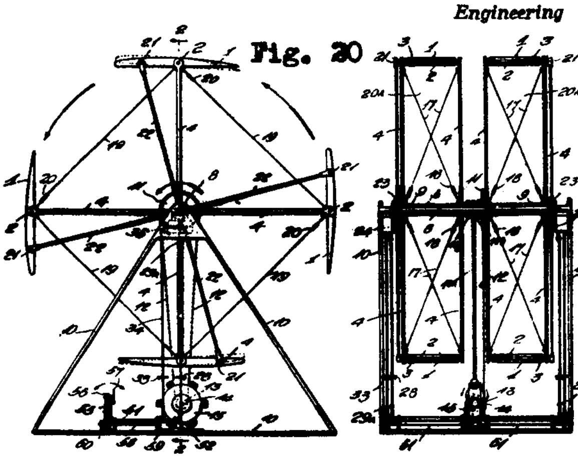


Fig. 21

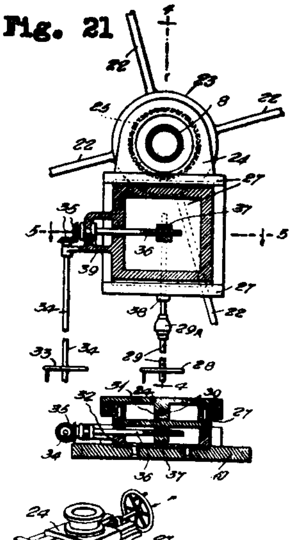
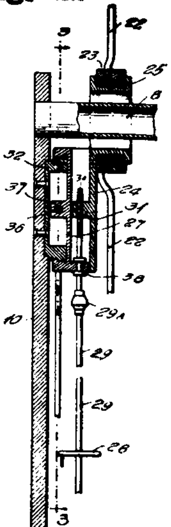


Fig. 22



Figs. 14-19.- Platt system.

Figs. 20-22.- Laskowitz system.